Software Design to Simulate FMCW Radar Signal: A Case Study of INDERA

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***Abstract*—Nowadays computer simulation plays a significant role in analyzing the radar signals. The research group at the Radar and Communication Systems (RCS) has developed a maritime radar, called INDERA, that works using the Frequency Modulated Continuous Wave (FMCW) technology. In line with the enhancement of the radar system we have also developed a software system that is able to be used for simulating the FMCW signal of radar INDERA. This work presents a design of the software that can be utilized not only to generate and analyze the FMCW radar signal, but also reconstruct the received radar signal onto a PPI (Plan Position Indicator) radar display. The software tool completed here will help us in analyzing the actual radar returns as well as the effects of surface scattering. The gained knowledge about the system characteristics in response to the abruptly changing situations is of great importance in extracting range information more easily.**

***Index Terms*—Simulation, FMCW, Radar, INDERA.**

I. Introduction

INDERA, which stands for Indonesian Radar, is a maritime radar that works using the FMCW technology [1]. A block diagram illustrating the principle of the FMCW radar is shown in Fig. 1. A portion of the transmitter signal acts as the refe-rence signal required to produce the beat frequency. It is introduced directly into the receiver via a cable or other direct connection. The beat frequency is amplified and limited to remove any amplitude fluctuations [2].

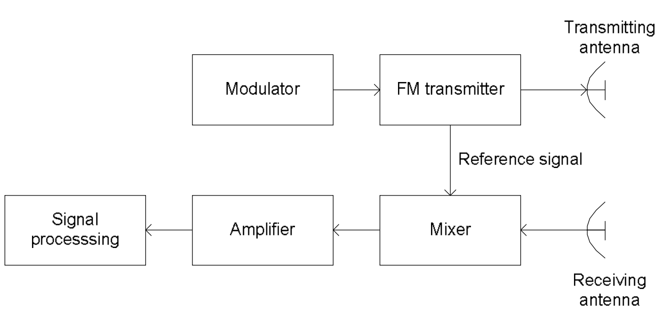

Fig. 1: Block diagram of the FMCW radar.

In the surveillance mode, INDERA is continuously trans-mitting modulated electromagnetic waves to detect targets in the surrounding area. Like other FMCW (frequency modulated continuous wave) radar, the frequency of the transmitted signal is changed in a known manner as a function of time. In the recent work INDERA uses the sawtooth shape modulation when transmitting out its signal (fig. 2).

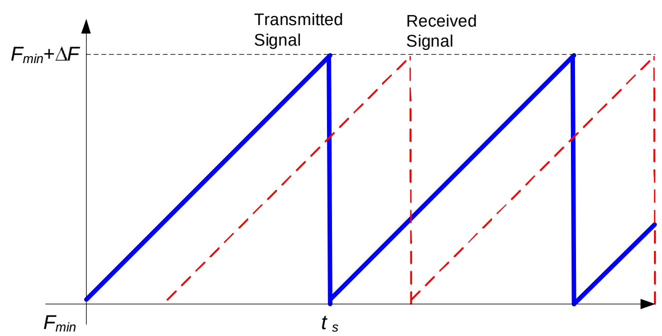

Fig. 2: Sawtooth shaped FMCW radar signal. The frequency of the transmitted signal is linearly increased about ΔF within the sweep time t_s.

By considering that a signal will spread in the air space at the speed of light c, the signal reflexion caused by a target at distance R from the origin of radar will generate a beat signal with frequency f_R [2][3]

$$f_R = \frac{2F_m}{c} R \quad \text{where} \quad F_m = \frac{\Delta F}{t_s}. \qquad (1)$$

Applying the Fourier transform we will obtain the spectrum of this beat signal. In frequency domain the range or distance of target from the origin of radar can be determined by measuring the distance of the signal peak from the axis origin.

In the analysis of radar signals a computer simulation plays a significant role. In line with the enhancement of the radar system we have developed a software system capable for simulating the FMCW signal of radar INDERA. This software tool system is designed not only to generate and analyze the FMCW radar signal, but also to reconstruct the received radar signal onto a PPI (Plan Position Indicator) radar display.

II. Software Design

This software tool is developed in response to the urgent need in the analysis of data of INDERA. The requirement for the proposed software tool is that it should be simple and easy to use. By satisfying the mentioned requirement the designed software will assist us in analyzing the actual radar returns as well as the effects of surface scattering. Keeping the requirement in mind we have designed a software tool whose operation is depicted by the flowchart diagram in Fig. 3.

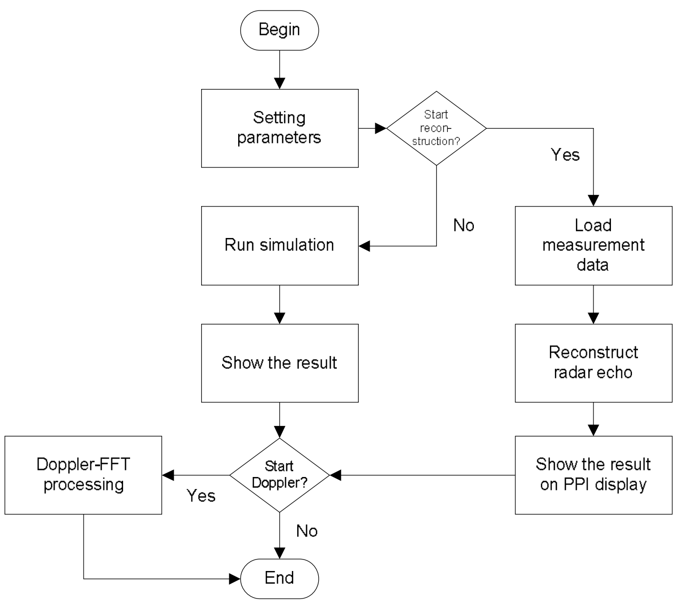

Fig. 3: Flowchart of operation of the software.

The operation of the developed software tool is divided into three successive steps necessary for processing the radar signals [3][4]. These steps are *pre-processing*, *computation*, and *post-FFT*.

In the *pre-processing* we have to prepare all necessary parameters needed for the reconstruction or simulation of signals captured by the radar's receiver antenna. Mostly, these include the setting of parameters of the hardware and signal characteristics that will be simulated or reconstructed.

In the *computation* the user can choose one of the available modes: simulation or reconstruction. In the simulation mode a radar signal will be generated using the previously defined parameters. Otherwise, in the reconstruction mode, a radar signal will be constructed by reading an extra file containing a series of radar measurement data. Once data has been available in the computer memory, it is ready to be transformed in the frequency domain. As shown in (1) the frequency spectrum is linearly dependent with the range of objects detected at the actual azimuth position.

Unfortunately, as shown in many cases, the result of the *computation* step is not satisfactory, since the level of noise or scattering contained in the signal is still high or non-negligible. Therefore, we must earnestly seek to address this problem. All arrangements needed to suppress the effect of noise or scattering on the achieved radar signal are provided in the *post-FFT*.

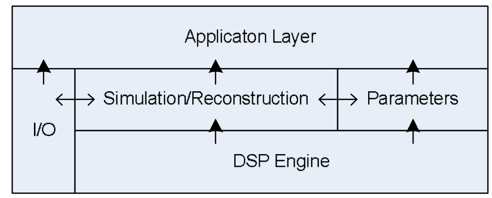

Fig. 4: Layered architecture of the developed software tool,

The layered architecture of our software tool is shown in Fig. 4. In this architecture model an arrow symbol represents a service direction [5]. Generally the lower layer will serve the upper layer, e.g., the layer of DSP engine will give all of its results directly to modules on the upper layer. A double ended arrow indicates that there is an extensive data exchange between the modules in the neighborhood layers.

The interaction between the user and the software system will always take place in the application layer. Nowadays this application layer is mostly implemented through a graphical user interface. So, from the user's point of view, it is very important to have a good user interface.

III. Graphical User Interface

The interaction between the user and this software tool is realized through a simple main display comprising only key panels directly related to the analysis or synthesis of signal of INDERA (fig. 4).

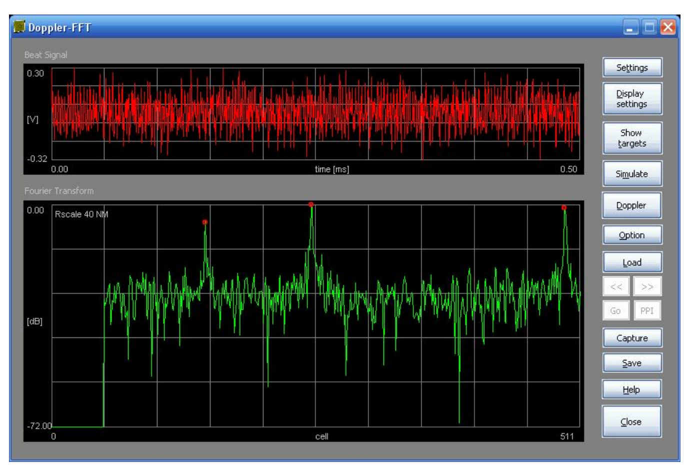

Fig. 5: Simple graphical user interface.

We divide the main display into two window areas: upper and bottom window. The upper window is reserved for displaying signal in time domain, whereas the bottom is reserved for its related magnitude spectrum. The right side of the main display is reserved for the key panels.

The range positions of simulated targets are highlighted by red colored circles that are overlaid on top of the peaks of the magnitude spectrum on the bottom window. The verification of a simulation can be shown by the coincidence between these red circles and the peaks in the resulted spectrum.

In the key panel area on the right side of the main display we will find all main buttons or commands necessary to start the task for the analysis, simulation, and reconstruction of radar signals. These key panels are functionally divided into four groups of command: *parameter settings*, *simulation*, *Doppler processing* and *signal reconstruction*.

In the command group *parameter settings* the user is requested to enter all values characterizing the incoming signal that will be encountered by the radar receiver antenna (fig. 6). This includes, e.g., parameters of the transmitted FMCW signal, analog to digital converter (ADC), Doppler processing, information related to the range and speed of targets etc.

The command group *simulation* consists only of one button. By pressing this button the user has confirmed the task to start the simulation immediately, i.e., a new radar signal will be generated according to the specifications previously defined by the user.

In the command group *Doppler processing* that also comprises one button we can compute the Doppler spectrum reflected by moving targets. This processing utilizes the fact that an approaching object will cause an increasing frequency shift. Such a frequency shift will be presented as a bright peak in the positive half plane of the Doppler spectrum. Accordingly, an object that is moving away from the origin of the radar will cause a shift in the frequency appears in the opposite half plane of the Doppler spectrum.

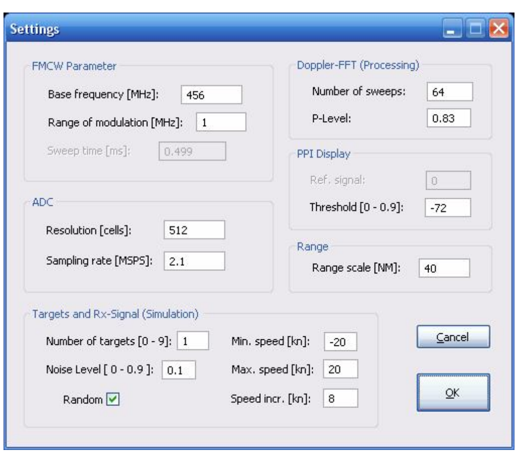

Fig. 6: Parameter settings.

The real advantage of this software tool is summarized in the command group *signal reconstruction*. In this command group we can read real data from radar INDERA. After successfully loading data into the computer memory, we can reconstruct radar signal captured during the last measurement, and successively show the result on the PPI radar display. Every data series at each azimuth position of the rotating antenna can be shown for analysis purpose. Furthermore, this software tool provides also an extra option that gives the opportunity for users to capture and save images in the simulation results into specific image files. Alternatively, all data of the simulation result can be exported to an ASCII text file.

IV. Simulation Result

In the following we present the simulation results using the above described software.

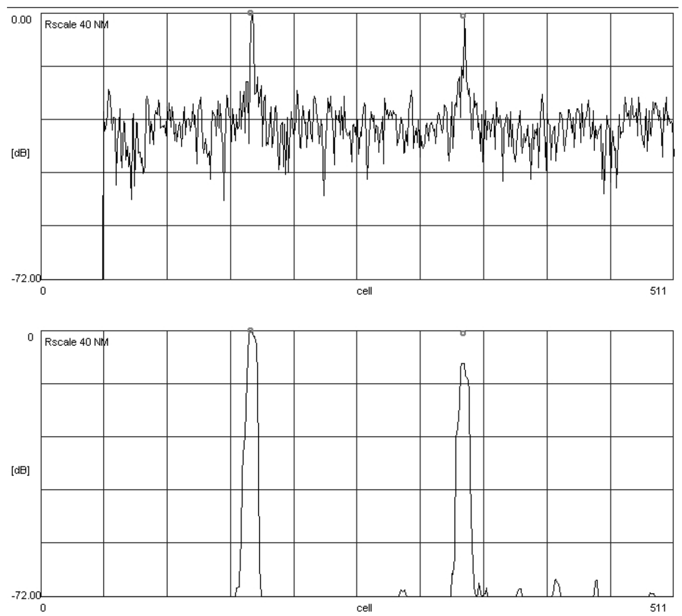

Fig. 7: Simulation of radar echo coming from two targets in the range scale 40 NM (1 NM = 1,852 m). Top: the magnitude spectrum of signals corrupted by surface scattering. Bottom: the magnitude spectrum of signals after the application of a peak search algorithm.

Fig. 7 shows the result of simulation of radar signal reflected by two targets in radial distance of 13.3 NM and 26.4 NM from the origin of radar. The range scale is set to 40 NM. The horizontal axis presents radial distance from the origin of radar resolved in 512 cells, whereas the vertical axis presents the magnitude of the spectrum in decibels. As shown in the top figure, we see that there is non-negligible part of noise or scatter contained in the spectrum of the radar signal. The application of a peak search algorithm on the magnitude spectrum can effectively suppress the effect of noise and surface scattering.

A simulation of two moving objects is shown in fig. 8. The determination of the speed of detected targets is implemented by performing the Doppler-FFT algorithm onto a series of data captured at a certain azimuth position of the radar antenna. For this purpose radar INDERA continuously transmit and receive a series of modulated signal, and successively perform the Fourier transform.

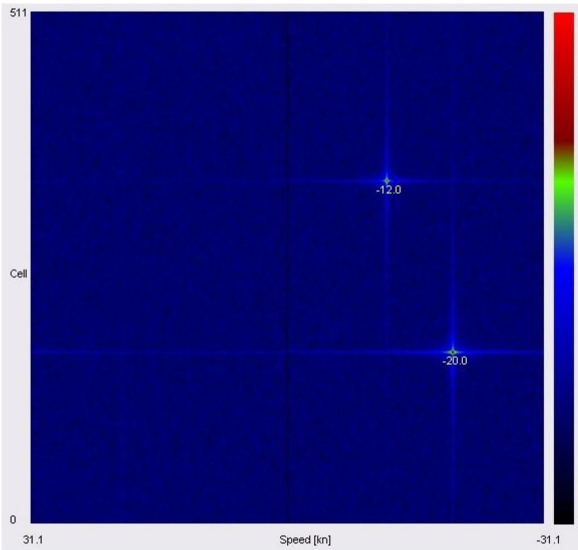

Fig. 8: Doppler spectrum of two objects moving away from the origin of radar.

Of a number of complex Fourier data we once again compute the final Fourier transform to obtain a two dimensional Doppler spectrum. In this Doppler spectrum we will see that approaching objects will trigger bright peaks in the positive half space of the spectrum. Consequently, objects moving away from the origin of radar will trigger peaks in the negative half space of the spectrum. As depicted in the Doppler spectrum in Fig. 8 we see two objects that are moving away from the origin of radar with speed of 12 kn and 20 kn (1 kn = 1.852 km/h).

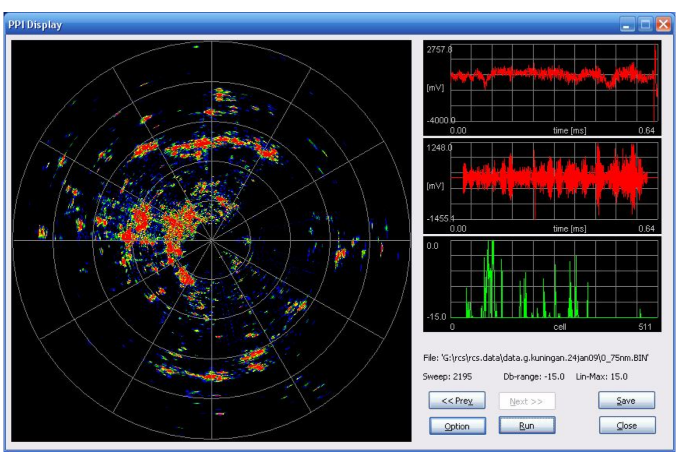

Fig. 9: Reconstruction of radar echo on the PPI display.

Apart from all the things associated with simulation, our software tool can also be used to read data of radar INDERA stored in a file, and at the same time to present it on the own PPI radar display. With this feature we have a proper means to reconstruct the radar echo and study various situations at the time of radar signal measurements.

Fig. 9 demonstrates a capability of our software tool in re-constructing radar echo on the PPI display from the past measurement data. In this figure we have used measurement data captured in the surrounding of RCS building complex. Each signal received by the radar antenna is shown sweep by sweep on the right side of the main display. By studying the individual signal at every sweep we can detect a possible source of hardware defect, or otherwise, make improvements to obtain a better result.

Despite many previously discussed advantages a realistic clutter data generator is not yet implemented in our recent work. In the future we are planning to include such clutter data generator into our software that is based on the sea clutter measurements from the sea and ocean in the Indonesian territory.

V. Conclusion

We have introduced a simple and easy to use software tool for simulating and reconstructing radar signal of INDERA. It is shown that this software system is a valuable means in analyzing the actual radar returns as well as the effects of surface scattering. In the future we plan to include the real measurement data into the simulation of sea clutter. The gained knowledge about the system characteristics in response to the abruptly changing situations is of great importance in extracting range information more easily.

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